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A transition perspective on alternatives to coal in Chinese district heating

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ABSTRACT

China uses half the world's annual coal consumption, since coal is the primary energy source for heating in urban areas, particularly in northern China. This entails significant challenges for urban air quality in China and for the global climate. Unlike the electricity and transportation sectors, the heating sector has received little attention from policy and research actors in China, despite very high penetration of urban district heating (DH) systems, which supply more than 80% of northern China's urban buildings. DH systems can facilitate efficiency improvements and the use of renewable energy sources. This study explores the dynamics and possibility to expand alternative energy sources (natural gas, biomass, direct geothermal heat, ground-source heat pump, municipal waste heat, industrial waste heat) for DH in China. We apply an analytical framework largely based on the multi-level perspective on socio-technical transitions, in which transitions are interpreted as the result of interactions between niche, regime and landscape elements. The study provides an integrated picture of the socio-technical structure and functioning of DH in China. The results show that an energy transition in Chinese DH systems has barely started. The system is characterised by stability of the coal-based DH regime, while a number of alternative niches are struggling to emerge. Among these, natural gas is the most successful example. However, at local level different niches present opportunities in terms of physical availability, economic viability and capacity to address landscape pressure. The introduction of an appropriate sustainable heat roadmap and policy framework at national level could promote and facilitate this energy transition.

Keywords:

District heating;
China;
Renewable energy;
Transition.
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1. Introduction

On cold winter mornings, the residents of Beijing wake up in a city trapped by smog. China's increasingly grave air pollution is experienced daily by millions of people across the country. The problem is even more acute during winter in northern China, where heating systems are needed [1]. In the provinces of northern China[i], where on average 80% of all urban buildings are connected to a District Heating (DH) network [2], DH could be used to reduce use of fossil fuel for heating. DH involves the distribution of heat from one or several heat production plants to a number of consumers in a city or town through a network of pipes. Due to the scale involved in DH, these systems provide a number of advantages over individual heating systems, including the opportunity to use renewable energy sources such as unrefined biomass and municipal solid waste (MSW), while also reducing primary energy demand by enabling combined heat and power (CHP) production and recovery of industrial waste heat [3]. Today, many European countries have constantly increased the share of renewable energy used in DH systems [4].

[i] Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shanxi, Gansu, Ningxia, Xinjiang and Qinghai.

Abbreviations:

CHP	=	Combined Heat and Power
CNOOC	=	China National Offshore Oil Corporation
CNPC	=	China National Petroleum Corporation
CUHSA	=	CUHA Chinese Urban Heating Association
DH	=	District Heating
GHG	=	Greenhouse gas
GSHP	=	Ground-source heat pumps
HAO	=	Heating Administration Offices
HOBs	=	Heat-only Boilers
IWH	=	Industrial waste heat
MEP	=	Ministry of Environment Protection of China
MOF	=	Ministry of Finance of China
MOHURD	=	Ministry of Housing, Urban and Rural Development of China
MLR	=	Ministry of Land and Resource of China
MLP	=	Multi-level Perspective
MDRC	=	Municipal Development and Reform Commissions
MSW	=	Municipal solid waste
NBS	=	National Bureau of Statistics of China
NDRC	=	National Development and Reform Commission of China
NEA	=	National Energy Agency of China
PM	=	Particulate matters
SMEs	=	Small to medium-sized enterprises

However, in China 97% of the heat distributed through DH networks is based on fossil fuels[ii], specifically coal about (82.3%) [5]. This roughly corresponded to 3.4%[iii] of national consumption of coal in 2011 [6,7]. Combustion of large quantities of coal in the proximity of highly populated areas for the production of DH affects environmental and human health standards in Chinese cities [1]. The Chinese national government has recognised the urgency of these challenges and adopted measures to further expand the DH network and improve efficiency in buildings and heat distribution through e.g. improved building codes and heat meter reform [8]. Emergency measures have been introduced at local level, especially in Beijing, to contain the problem. However, DH in China remains largely dependent on coal, despite the population (timidly) expressing disapproval of the deteriorating environmental and health conditions in all main cities.

The aim of this study was to explore the dynamics and possibility for an energy transition in the Chinese DH system, increasing the use of alternative energy sources and reducing the reliance on coal. To achieve this aim, we examined the structure and functioning of the Chinese DH system at national level and sought to identify the socio-technical feasibility of expansion of alternatives to coal-based DH systems in China.

Previous studies of Chinese DH have addressed the technical feasibility and potential energy savings of integrating heat pumps [9], seawater [10], direct use of geothermal [11], biomass gasification [12] and industrial waste heat [13,14]. Systems studies have analysed the integration of waste heat, electric heat pumps and natural gas to achieve a clean technology transition in the Chinese DH system [2,15]. Previous studies have also examined the institutional mechanisms of the Chinese DH system [16]. However, a comprehensive study of fuel switch dynamics based on the socio-technical aspects of an energy transition in the DH system is lacking. An integrated perspective on the energy planning in the sector is considered important to facilitate transition [17].

[ii] In 2011 the total heat supply was 2.81 EJ, in which the fossil fuel sources share 97%, i.e., 1.24 EJ from coal-based CHP and 1.48 EJ from coal- and gas-based heat boilers [7].

[iii] Total coal consumption in China was 2.4 billion tons of standard coal (70.5 EJ) in 2011.

Here we applied a transition framework to assess the future potential of innovations that can grow into a new system through large-scale diffusion. The framework is based on the multi-level perspective (MLP) [18,19], which interprets transitions as the change from one socio-technical regime to another. The framework's objective is the identification of factors that support innovation diffusion and critical barriers that may hinder it. However, the framework is qualitative in nature and does not aim to give precise predictions regarding the rate and speed of diffusion, but is able to gauge the future potential of emerging technologies in a qualitative manner. The data for niche innovation system and niche-regime anchoring analysis were collected through academic publications, reports and governmental documents both in English and Chinese. Additional data were collected through semi-structured interviews in Beijing in 2013, including heating reform office in MOHURD, Chinese district heating association, China geothermal association, Danish district heating association (Beijing office), Swedish district heating association (Beijing office), and experts in the alternative energy sectors, including Tsinghua University, Beijing Forestry University and China Academy of Building Research. In most cases, the interview results were used as a complement to the data collection or a source to acquire data and documents.

2. District heating in China

Today China has one of the most extensive DH networks in the world. The history of district heating in China started in 1950 with the first Five-Year Plan. The size of the DH network remained negligible until 1986, when a change in policy priorities promoted rapid expansion that is still continuing, with a growth rate averaging 9-17% per year in recent decades (Figure 1).

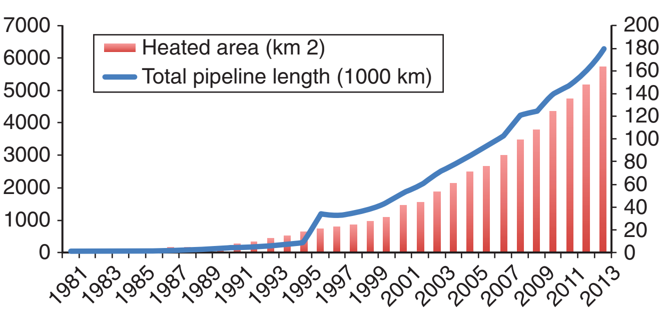

Figure 1: Floor area and total pipeline length in the Chinese DH system (1981-2013).Source: [20].

In 2013, DH supplied 5717 km^2 floor area through a network of 178,136 km of pipes in the provinces of northern China [20].

The DH sector is organised as a monopoly through China's top-down government [16]. At the national level, the Ministry of Housing and Urban-Rural Development (MOHURD) and the National Development and Reform Commission (NDRC) are two of the most influential public actors. The NDRC's function is to formulate energy policies (also through the National Energy Agency) that influence the development of the DH sector, such as energy efficiency and renewable energy policies and programmes [16]. The NDRC, in coordination with MOHURD, is also responsible for the establishment of general guidelines on the DH pricing policy [21]. The responsibility of MOHURD is to implement NDRC policy guidelines and formulate specific sector policies. Another important actor at national level is the Chinese Urban Heating Sector Association (CUHSA). Established in 1987 by the Beijing municipal heating company, the CUHSA functions as a key actor in sharing experiences and information among its members (municipal heating companies, equipment suppliers and researchers) and an advocate for the heating industry [22]. At local level, municipal governments play key roles. In most cities, the deployment of DH networks is the responsibility of Heating Administration Offices (HAO), usually under the Department of Construction, or the Public Utilities Bureau. In collaboration with the Municipal Development and Reform Commissions (MDRC), the local branches of the NDRC, HAOs are responsible for issuing construction and operation permits.

In this regard, the DH sector has remained largely untouched by the marketization process that characterised many sectors in the Chinese economy in recent decades. DH is provided as a form of social welfare to protect vulnerable groups. While the heat supply is ensured for the sake of social sustainability, the heat production side is subject to market rules. Heat production costs float according to the market price of energy, particularly coal, while the heat price are usually lower than the production cost and heavily subsidized from the municipal budgets. In 2005, the NDRC issued guidelines to link the price of coal with that of DH [21]. As a result of this complicated and overly bureaucratic system, the price of DH is now dependent on the type of provider or energy source used, and varies greatly within and between cities [23].

With the adoption of the Urban Heating Reform in 2003 [24], the process of marketization was initiated throughout China. The primary goal was replacement of the area-based billing system with a consumption-based system. However, more than ten years after implementation, the results of the reform are still modest [16].

The DH sector remains highly fragmented and, despite recent progress in consolidation of small providers into larger commercial companies [16], still has a large number of DH providers and heat suppliers in each city [25]. Providers can be of different forms, from state-owned enterprises (usually supplying large urban areas), public utilities (responsible for smaller networks) to private companies [26].

3. Analytical framework for studying future energy transitions in DH systems

The analytical framework employed in this study relies largely on theories and approaches developed within the literature on socio-technical transitions, with MLP being an important approach [27, 28]. A first challenge when applying MLP to study DH is delineating the boundaries of the system under analysis. In transition studies socio-technical systems traditionally comprise: (i) a technological system of material and technical artefacts; (ii) a social system formed by networks of actors and social groups; and (iii) an institutional system, which includes the formal, normative and cognitive rules that guide the activities of these actors. In this study, we delineated the boundaries of the system under analysis by focusing on two components of the DH supply chain: the supply of energy and its transformation into heat (see dashed box in Figure 2). Consequently, the system under analysis consists of, (i) the technical components (technologies and artefacts) relevant for energy supply and transformation, (ii) the social components (actors and networks) using or influencing the use of these technologies and, finally, (iii) the institutions affecting the activities of these actors.

The MLP approach views transitions as the outcome of interactions between three levels: regime, niche and landscape (Figure 3). Socio-technical regimes represent the dominant way of fulfilling societal functions [29]. We considered coal-based DH to be the socio-technical regime, since coal has been the undisputed energy source in Chinese DH. A second major element in the MLP is the socio-technical niche, which forms the socio-technical environment where novelties emerge [28,30]. We defined niches as alternatives to coal-based DH and, through a review of the literature on DH systems and interviews with actors in the Chinese DH sector, we identified a set of six for inclusion in the study. These were DH based on: natural gas, biomass, municipal solid waste (MSW), direct geothermal heat, ground-source heat pumps (GSHP) and industrial waste heat[iv].

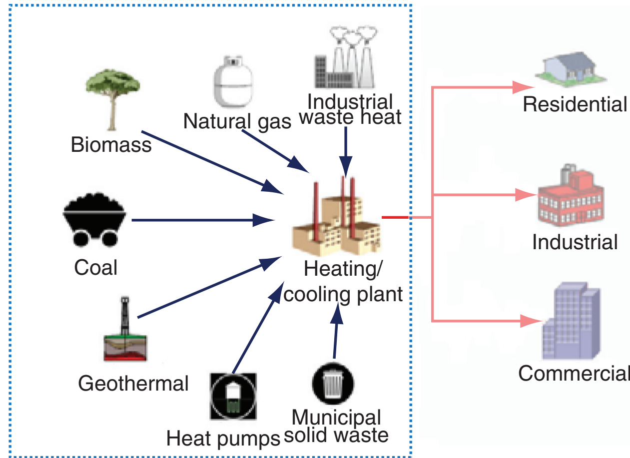

Figure 2: Simplified representation of the Chinese DH system. Note: Dashed box highlights the boundaries of the system covered in this study.

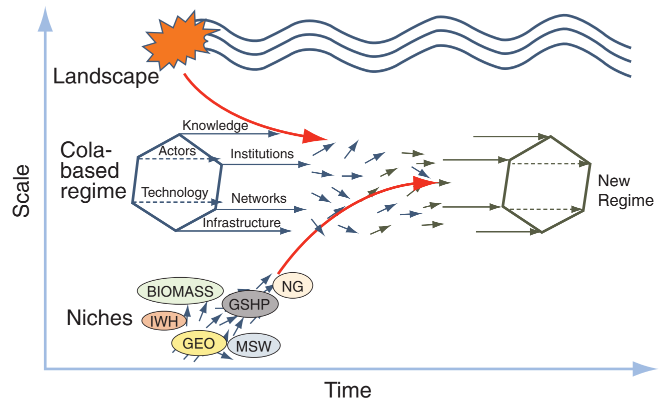

Figure 3: Multi-level perspective on transitions. Adapted from Geels [19].

iv Other alternatives such as nuclear, solar, wind energy and electricity might be technically feasible, but are not considered in this study due to concerns about infrastructure and sustainability issues.

Finally, the landscape includes all exogenous factors that affect the development of niches and regimes, but are largely outside the influence of niche and regime actors [19,31]. Here we focused on three major landscape factors connected to the social discontent with environmental quality, mitigation of climate change and the increasing demand for indoor heating.

A typology of transition pathways based on the type and timing of interactions between niches, regime and landscape has been suggested by Geels and Schot [32]. The classical case is that of *substitution*, which occurs when landscape pressures create 'windows of opportunity' for niches that are sufficiently developed to exploit the opportunity, which then diffuse and eventually replace incumbent regimes [19] (see Figure 3). We developed an analytical framework to assess each alternative (niche) and identify barriers and opportunities for their diffusion in the DH system. The framework is based on the idea that the likelihood of diffusion is affected by the socio-technical structure of the niche and the interactions between the niche and the incumbent regime. We analysed the socio-technical structure of niches by examining: (i) material and technical artefacts; (ii) networks of actors and social groups; (iii) institutions; and (iv) infrastructure. The first three elements are suggested in the MLP approach [19], while the fourth, infrastructure, is our addition[v]. Infrastructure covers the physical and material aspects of the systems. Its inclusion is justified by the specific features of DH systems, e.g. spatial location of networks, geographical limitation of energy resources and distribution systems, etc.

The analysis of the interactions between niches and regime was carried out in terms of niche-regime translation. The assumption was that niche development is not a matter of simple up-scaling, but of making a broad variety of connections between niche and regime [33]. Elzen et al [33, 34] suggest that the anchoring of socio-technical practices in an existing regime facilitates the transition process and identify three forms of anchoring; technological, network and institutional. Inspired by these studies, we defined anchoring as the process by which a novelty becomes newly connected, or connected more firmly, to a regime. The further the process progresses, i.e. with more connections, the larger the chances that anchoring will eventually develop into durable links supporting the expansion of the niche. In our framework we considered three types of anchoring:

(1) *Social* anchoring[vi], which is dependent on (i) the extent niche actors are present in the regime, i.e. hybrid actors; and (ii) the level of collaboration (or conflict) between niche and regime actors.
(2) *Institutional anchoring*, which is affected by (i) the existence of market space for the niche in the DH system and thus its competitiveness against the regime; and (ii) the impact of regime institutions on the potential diffusion of the niche ranging from obstructing to allowing and supporting.
(3) *Technical* anchoring, which refers to (i) the type of relationship between the knowledge and technology of the niche and those of the regime (this can be competitive, compatible or dependent); and (ii) the capacity of niche technical artefacts, concepts and practices to address tensions (or exploit opportunities) created by landscape factors.

4. Coal-based DH system – the regime

Coal has been the unquestioned source of energy for DH in China since these systems were first deployed in the 1950s. With a share of about 82.3% of the heat supply in DH [5], coal-based DH is the stable way of supplying indoor heating in northern China. Technical, social, institutional and infrastructural factors contribute to the stability and path dependency of this regime.

4.1. Infrastructure, actors and technologies

With 19% of the total global proven reserves, China is rich in coal. In 2013 it consumed nearly half the world total, 72.5 EJ (low-heat value) [20]. Although traditionally a net coal exporter, since 2009 the country has become a net importer. In that year imports accounted for only 4% of domestic coal consumption, but these volumes represented 15% of the global coal trade [35]. The production of coal (upstream system) is carried out in China by a large number of public and private mines. Due to recent consolidation of the industry into a small number of larger mining groups, the sector has become less fragmented. According to China's coal industry association [36], in 2013 the top four and top ten coal producers having 25% and 40%, respectively, of the market.

[v] Inspired by the most recent literature on Technology Innovation Systems, in which infrastructure is considered part of the structure of innovation system [97].
[vi] We refer to social instead of network anchoring since we chose to limit our scope to actors due to the difficulties of identifying and examining informal networks in such an extensive system such as the Chinese DH system.

The actors involved in the transformation of coal into heat (downstream system) are large power companies, for which heat is a co-product of electricity production from CHP plants, and large DH providers, which generally own CHP plants and large HOBs. However, each city also has a large number of medium and small providers of coal-based DH. These traditionally employ small HOBs for DH production [16]. Overall, the share of HOBs in DH has been stable in the past decade (Figure 4). However, since HOBs have lower energy input/output efficiency (60–65%) [37] and consequently higher heat production costs than CHP, expansion of the share of coal-based CHP is seen by the national government as one of the main strategies to improve the efficiency of heat production.

4.2. Institutions

The coal sector in general and the coal-based DH system have experienced substantial changes in the past two decades, in response to the concern of actors, in particular the national government, Important policies have included, energy efficiency improvements in coal-fired thermal power plants, containment of total coal consumption and promotion of clean coal technologies. Since 2000 with the adoption of the “Revised Regulations for CHP Development” the national government has promoted the deployment of CHP [38]. “The Small Plant Closure Program” established by the 11th Five-Year Plan (2006–2010) is a key policy requiring municipal governments to decommission small coal HOBs and replace them with larger plants. In addition, the national government has sought to limit overall consumption of coal by introducing a general cap of 4.2 billion tons by 2020 [39]. Growth in coal consumption has been slowing down, from an average of 6.1% per year in 2007–2011 to 2.6% in 2012–2013 [20]. In 2014 coal use declined for the first time, by 2.9% [40]. Finally, the promotion of 'clean' coal technologies has been another key institutional component of the coal regime. There is general support for the transformation of coal into gas, oil and olefins and the application of measures to reduce emission of air pollutants and GHGs from coal supply and combustion phases. In 2012, 92% of coal-fired power plants (including CHP) were equipped with sulphur removal technologies at 90% average efficiency, while only 27.6% had NOx removal equipment at 48% average efficiency [41].

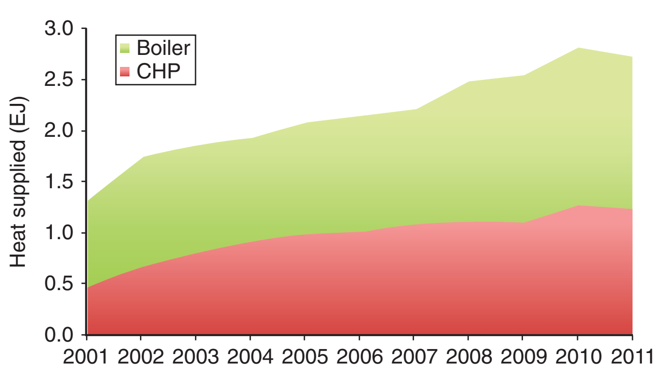

Figure 4: Heat supplied by CHP and HOB to Chinese DH (2001-2011). Source: [20].

A key feature of the coal industry is the marketization which started a decade ago. Since 2006 the price of thermal coal for utility use has been fully subject to market pricing. According to national guidelines [42], thermal coal contracts for utility use should be directly and independently negotiated between coal producers and power plants, without state intervention. This was the last step in deregulation of coal pricing in China.

In sum, the coal-based DH system is characterised by stability and path dependency. The factors contributing to this are the availability of abundant domestic reserves of coal and increasing efficiencies through a trend towards larger actors (both in downstream and upstream parts of the system), the diffusion of CHP and large HOBs and the application of clean coal technologies. However, the introduction of stricter environmental regulations and the adoption of regional and national caps on coal consumption undoubtedly create challenges to the dominance and stability of the socio-technical regime.

5. Changing landscapes

The DH system is influenced by the landscape, which contains factors outside the control of regime and niche actors. These factors can generate dynamics which consolidate or challenge the stability of the regime and the emergence of niches. Here we do not attempt to quantify these impacts, but limit our interest to qualitative evaluation of a set of three factors:

vii WHO recommended levels of PM2.5 are below 25 _g/m3 [98]. Air pollution due to PM2.5 is associated with diseases such as respiratory infections, heart disease and lung cancer [99].

Other alternatives such as nuclear, solar, wind energy and electricity might be technically feasible, but are not considered in this study due to concerns about infrastructure and sustainability issues.

(1) Social discontent with environmental quality. Urban air pollution in Chinese cities made headlines around the world in early 2013, when record levels of small particular matter ($PM_{2.5}$) above 900 µg/m^3 were recorded in Beijing [43][vii]. The increasing levels of air pollution experienced throughout China in recent decades have led to growing discontent among urban and rural residents. The number of reported environmental protests grew from 50,000 in 2005 to 180,000 in 2010 [44]. As social discontent with air quality and environmental conditions skyrockets, it inevitably generates pressure on coal-based DH since coal combustion has been identified as one of major causes of pollution in urban areas [5].

(2) Interest by the national government in GHG emission reductions. In 2007 China became the largest global emitter of GHG. The government has recognised its responsibility and in 2010 introduced national reduction targets as an effort to address global climate change [45]. In 2014, it pledged that the country's emissions will peak around 2030, if not earlier [46]. This will require substantial savings from the energy sector. In a context where reductions in coal consumption and coal-related emissions are seen as a key contributor to the climate targets, the DH regime will be subject to further pressure.

(3) Growing urbanisation and increasing standard of living. Currently about half of the world's new buildings are being constructed in China and the scale of urbanisation is unprecedented in human history. The share of urban population increased from 11% in 1950 to 54% in 2014, and is expected to reach 70% by 2030 [47]. An increasing urban population and higher heating demand per inhabitant have had a massive impact on residential urban energy consumption, which tripled between 1996 and 2008 largely due to the staggering increase from heating demand [48].

The first two landscape factors are interpreted here as generating pressure on the coal regime. This is apparent at local and national level, with governments promoting alternative sources of DH, forcing coal plants to move outside the city boundaries, introducing national and regional coal consumption caps, and promoting improvements in coal-fired thermal power plants. However, the third factor, further increased heating demand, is expected to have a dual impact on the coal regime, by contributing to regime stability since coal-based DH is the only system able to supply the large quantities of heat required by the scale of these dynamics, but also by creating market space for the deployment of alternative DH systems (niches).

6. Alternatives to coal-based DH – niches

It is possible to envisage a large number of alternatives to coal for supplying heat to DH systems in China. In this study we considered six alternatives (natural gas, biomass, municipal solid waste, geothermal energy, ground-source heat pumps and industrial waste heat). Each alternative was interpreted as a socio-technical niche and evaluated with attention to its structural components and the interactions with the coal regime[viii].

6.1. Natural gas

Natural gas provides around 6% of China's primary energy supply and this is expected to grow to 10% by 2020 [49][ix]. The majority of the gas consumed in China is of domestic origin. Domestic conventional gas reserves are 68,000 billion cubic metres (bcm) (2650 EJ), with proven reserves of 40,000 bcm (1559 EJ) and exploited gas 12,000 bcm (468 EJ) [50]. However, since 2006 imports have become increasingly important. In 2013 they accounted for 31.6% of domestic consumption [51]. Imports reach the Chinese market as liquefied natural gas (LNG) via major ports, or through the pipeline infrastructure connecting China with neighbouring countries. Several pipelines are planned to increase the import volume (e.g., from Russia).

However, only a small share of the gas consumed in the country is used for DH. Most is consumed by the industrial sector, chiefly for power and heat production [52], while the power sector demand for gas is currently limited to peak load adjustment or to cover power shortages [53]. The share of natural gas in DH was roughly 15% in 2010 [2].

The upstream part of the system is characterised by dominance of a small number of large companies. These

[viii] Note that data on the economic and technical potential of niches are given only as exemplary cases to understand the transition dynamics among different niches. The cost of niches are average national energy retail prices with subsidies included and do not reveal the complexity of price variation influenced by different supply chain, product quality and category. Similarly, niche potential to deal with landscape pressures is an estimate and does not take into account different technical and efficiency levels adopted by enterprises.

[ix] We did not consider unconventional gas such as shale gas and coal-bed methane, since they still face technology challenges to reach commercialization in China.

include three national oil companies: China National Petroleum Corporation (CNPC), Sinopec and China National Offshore Oil Corporation (CNOOC). The downstream market is highly fragmented, with a large number of local wholesale suppliers of gas to industrial (e.g. DH production) and residential users.

Some of the most prominent barriers to expansion of the use of natural gas are supply constraints, access to infrastructure and the intricate price mechanism [54]. Gas pricing is currently regulated by NDRC, which aims to avoid inflation and encourage the use of gas. However, Chinese customers in some areas pay relatively high gas prices compared with other non-OECD countries [54]. In 2013, NDRC introduced "net back pricing" to move the pricing point downstream from the wellhead to the city gate [55]. Under this new mechanism, domestic gas prices will gradually align with prices of LPG and oil imports, while the oligopoly of gas transportation and distribution will remain under government supervision. China's gas infrastructure lags far behind its demand requirements. Even if CNPC succeeds in doubling the current transmission pipelines in the next five years, China would still have less pipelines than Germany, with a demand that is 2.5-fold higher [54].

The gas niche maintains intense interactions with the coal regime. Evidence of anchoring can be found in the downstream part of the two systems, social: hybrid actors who produce DH from gas and coal boilers; institutional: coal-to-gas boilers policy in main economic zones; and technological: compatibility of the two combustion-based technologies. However, our analysis of the institutional interactions revealed that use of natural gas for DH production is not competitive against coal. In 2013 the average ceiling price of gas at the city gate for industrial users was between 2.09 and 2.95 RMB/m^3 (53.6–75.7 RMB/GJ)[x] [56], while the steam coal composite average spot price (Bohai-Rim Steam-Coal Price Index, July 31, 2013) was 570 RMB/t (27.2 RMB/GJ)[xi] [57]. Both gas and coal prices fluctuated in the last few years. Finally, a positive anchoring is due to the capacity of the knowledge and technology of the gas niche to address landscape pressure. Use of gas in CHP and HOBs generally emits less air pollutants (less than one-third of NOx and 1% of SO_2) and half the GHG emitted by coal boilers [58].

In summary, the gas niche shows significant potential for expansion in the near future. Despite its poor economic performance against coal DH, the niche has been strongly pushed at local level by stringent regulations enforcing coal-to-gas boiler replacement. This process has facilitated diffusion of the gas niche through the technological compatibility between coal and gas boilers and the ability to address landscape pressure. However, further diffusion of the niche will be determined by the oligopoly feature throughout the supply chain, the economic variability of gas to end-users and the gas infrastructure capacity.

6.2. Biomass

With China shifting away from an agriculture-based economy to an industrial economy, the role of traditional biomass as a heating source has become less dominant. According to NDRC, residues from agriculture and forestry can supply an estimated 145.5 EJ of heat annually [59]. However, only 0.044 EJ (1.5 million tons standard coal) were supplied by pellet fuels (mainly from straw) in rural and urban areas in 2010 (12th Biomass Five-Year Plan)[60]. The target for biomass is 50 km^2 of urban floor area heated with biomass-based DH by 2015. This is roughly about 0.87% of the total area currently covered by DH (5717 km^2 in 2013).

Biomass is transformed into DH by employing CHP and small-scale HOBs. The primary feedstock is compacted biomass fuel, mainly straw [61]. Key features of this feedstock are its dispersed form and limited availability. The dispersed feature of feedstock makes investment by large energy enterprises less attractive, so the companies supplying biomass are mostly small to medium-sized enterprises (SMEs) [62]. In 2010 there were about 250 pellet producers [63]. Another challenge to expansion of biomass use for DH is the industry's low standards for market entry, as the regulatory criteria regarding raw material, equipment quality and emission standards are still under development. To ensure the quality of biomass boilers used in the demonstration projects proposed in 2014–2015 [64], the National Energy Agency and the Ministry of Environment required pellet boilers to comply with the same or better emissions standards than natural gas [65].

[x] In 2013, the gas pricing had two categories: the price of existing gas volume (2012 gas sales for non-residential sectors, 2.09 RMB/m3) and the price of incremental gas volumes (in excess of 2012 volumes for non-residential sectors, 2.95 RMB/m^3). These two categories have been merged into one in 2015.

[xi] 1 ton of raw coal equals to 0.714 ton of standard coal.

The biomass niche shows intense interactions with the coal regime. The social components of the two systems interact primarily in the downstream part of the system, where niche actors (DH providers) often own HOBs that are fuelled exclusively with biomass or co-fire biomass with coal. For this reason they can be seen as hybrid actors, which should be regarded as a special case as far as sustainability is concerned. For instance, co-firing biomass and coal is forbidden in biomass heating boiler demonstration projects [65]. In the upstream part of the system, biomass suppliers (usually SMEs) are not involved in the extraction and distribution of coal for DH.

As regards institutional anchoring, our analysis showed that the biomass feedstock is not cost-competitive against coal. A study [66] suggests that the price ratio between pellets and coal, although steadily decreasing in the past decade, is still very high. The average retail price of pellets was 950 RMB/ton (56 RMB/GJ) in 2012[xii], compared with 27.2 RMB/GJ in 2013. However, intense policy support provides institutional anchoring to the regime, particularly through the coal-to-biomass boiler policy in the three main economic zones and the biomass heating demonstration projects 2014-2015.

However, the major form of anchoring appears to be connected to technology and knowledge. Combustion boilers used in the two systems are highly compatible, which facilitates use of biomass in DH and, at the same time, helps the coal regime to mitigate landscape pressure. For instance, in one case in China [67], heat generation by pellet boiler (mainly straw) in CHP and HOBs emits less air pollutants (similar NOx, 93% less SOx) and GHG gases (80% less CO_2 ton/year) than coal boilers.

The opportunities for diffusion of the biomass niche in DH are linked to the intense interaction with the regime in terms of technology, actors and institutions. However, beyond the anchoring process, the niche is challenged by infrastructural components of the system such as limited feedstock availability and industry compliance with higher standards for market access.

6.3. Direct geothermal energy

DH systems can be supplied with the heat harvested from geothermal sources. Geothermal energy can be categorised as low temperature (less than 90 °C), intermediate-high temperature (between 90–150 °C) and high temperature (above 150 °C). According to the Ministry of Land and Resource of China (MLR), the conventional geothermal resources of sedimentary basin major plains amount to 25,595 EJ (853.19 billion tons standard coal), all intermediate and low temperature geothermal energy [68]. Most of these resources are located near the east coast and in the west of China [69].

According to the International Geothermal Association, geothermal DH capacity has continued to increase at about 10% annually in China, amount to 14,798.5 TJ/yr in 2009 [69]. In 2009, it supplied 12 km^2 of floor area, half of which went to homes of at least 1 million people in Tianjin City [69]. However, this is only roughly 0.2% of the 5717 km^2 heated with DH in 2013. The first policy official target was established only in 2013, requiring 500 km^2 of floor area to be heated with geothermal-based DH, including GSPH, by 2015 [70].

The oil industry has played an important role in the deployment of geothermal DH systems. Utilising these geothermal resources generally requires resource evaluation, drilling in different reservoirs and application of close-loop systems to carry reject water back to reservoirs [11]. These systems are capital-intensive and require large initial investments for production and injection wells, while the operating costs are relatively low, about half those of coal boilers [69]. The oil industry has the capital and knowhow to deploy these systems. Sinopec is now the leading company in the geothermal DH sector in China, with more than 6 km^2 of floor area developed [11]. In addition to demonstration projects, Sinopec has established itself as a reference research actor, launching the National Geothermal Energy Utilisation Research and Technology Development Centre in Beijing.

Our analysis of the interactions between the niche and the regime showed limited activities. Niche actors involved in the extraction and distribution of geothermal heat, primarily oil companies, do not have important interactions with actors in the coal regime. This is caused to some extent by the lack of technological anchoring. Technologically, the niche and the regime are not compatible, since utilisation of geothermal energy is based on mechanical systems, while coal

[xii] 1 ton of biomass (straw) equals to 0.578 ton of standard coal [100].

boilers are combustion based. An opportunity for the expansion of the niche is given by its capacity to address landscape pressure. For instance, new geothermal plants applying binary technology emit almost zero GHG emissions and air pollutants [71]. Finally, it is important to stress that geothermal DH in general is rarely competitive against coal-based DH, mainly because the resource is highly dispersed and entails high risks in the drilling phase. However, operating costs are very low and make the niche competitive where geothermal resources of good quality are readily available. For example, in the city of Xiongxian, 17.7RMB are saved in the operating phase for every m^2 of geothermal DH used to substitute coal-based DH [72].

In summary, the geothermal niche is significant in dealing with landscape pressure. However, our analysis showed that there is limited interaction between niche and regime. The niche expansion has largely been supported by large industrial actors. Policy support for the niche has only been recently introduced, and challenges remain in niche development itself. These include the regional availability of geothermal resources and the high upfront investments.

6.4. Ground-source heat pump

Extraction of shallow geothermal energy is the most common way of using geothermal energy in China. This type of geothermal energy refers to the solar energy harvested at shallow depth in the Earth and sewage waste heat recovery. The potential contribution in DH regions is high, around 111.7 EJ [68]. The technology used to extract shallow geothermal energy is based on ground-source heat pumps (GSHP). Depending on the heat source, it can be characterised into (i) ground-coupled heat pumps which extract heat from soil and bedrock, or (ii) groundwater and surface water heat pumps (including sewage, lake, river and seawater). All these types of GSHP are deployed in China and their application is usually not as geographically dependent as conventional geothermal energy [73]. However, the availability and quality of groundwater and surface water is a major concern in water-constrained regions.

By late 2012, more than 5000 GSHP systems were installed countrywide, 80% of which were in north and north-east China, where hot summers and cold winters dominate. The building area with GSHP systems installed exceeded 1400 km^2 [74] [xiii]. This is roughly 2.4% of the total area currently heated with DH.

The 12th Five-Year Plan established a target for GSHP of 350 km^2 of floor area by 2015 [68]. To promote pilot projects and market expansion, a package of policy measures was introduced at national level [75]. However, national guidelines for authorisation and resource exploitation are still lacking. At local level institutional settings differ greatly. In some regions/cities the exploitation of low temperature geothermal energy is widely supported through subsidies, tax reductions, standards, market entry requirements, networks and other institutional tools. The city of Shenyang, which accounts for 36.3% of all GSHPs installed in China, offers an important example of successful policy implementation [76]. At the same time, other regions/cities have introduced important limitations to the utilisation of GSHPs. According to the interview, this can be seen as a consequence of the niche's historical development. In the early years, lack of regulation resulted in the market booming from GSHP SMEs, and the diffusion of open-loop GSHP applications without adopting water reinjection technology or close-loop GSHP [77]. In response to this situation, cities where water scarcity was a concern, e.g. Nanjing, banned groundwater-based GSHP [78]. In recent years the market has matured and the close-loop GSHP has become increasingly popular.

Our evaluation of niche-regime interactions revealed a limited range and intensity of interactions. There are no significant interactions between the niche actors, i.e., GSHP SMEs active at local level, and coal-based DH providers and coal suppliers. As regards institutional interactions, the niche is economically competitive against the regime. High upfront costs, on average 1-3 times greater than coal-based DH systems, are compensated for by operating costs between 30% and 70% lower [79]. Moreover, public policies support niche expansion at national level and, in some regions, also at local level. However, there are important technical and institutional barriers regarding water use and pollution in water-scarce regions. Finally, the technologies employed in the niche are fundamentally different from those of the regime. The GSHP employs a mechanical system, while coal-based DH is combustion-based. A final element is the capacity of the niche's technologies and knowledge

[xiii] These values refer to individual application of GSHP as well as DH and cooling applications.

to address landscape pressure. GSHPs normally use one unit of electricity to move three units of heat [80].

In summary, this niche is well developed in some regions. It currently enjoys public policy support at national level and in some regions. Moreover, the niche is economically attractive and widely available throughout northern China. However, important barriers to further expansion in DH beyond pilot cities are technology quality control and appropriate regulation of GSHP installations.

6.5. Municipal solid waste

DH systems can be supplied with heat produced from incineration of waste, particularly, MSW. In China, the quantity of MSW collected every year is growing with urbanisation and changing living standards. Most of the MSW collected is currently landfilled [81]. However, since the 2000s the share of MSW incinerated has rapidly increased and 20% of total MSW was incinerated in 2010 to produce 1.7 GWh of electricity [60]. A co-product of electricity production is the generation of large quantities of heat, which are released into the environment [82].

The deployment of waste-to-energy (WTE) facilities is a key component of national and local strategies to handle MSW, especially where space for landfill is limited [82]. Small utility companies have entered the sector, attracted by high returns on investment [83], but their interest in MSW incineration is limited to production of electricity. The 12th national Five-Year Plan for MSW sets a target for MSW incineration of 35% by 2015 [84]. Support measures to achieve the target include loan programmes, guaranteed tariffs for renewable electricity, R&D on renewable electricity generation and exemptions from corporate income tax for 5 years [84].

However, MSW incineration remains a controversial method of waste disposal due to environmental and human health concerns about emissions of PM, gaseous pollutants, and dangerous substances (e.g. dioxins, toxic heavy metals etc.) [85]. Technologies to limit air pollution, such as semi-dry scrubbing and activated carbon injection to remove volatile metals and organic compounds and fabric filter bag housing to remove PM, are widely employed in China [82]. These technologies are similar to those used in the US and EU [86]. However, primary measures, i.e. processes that limit the formation of pollutants, especially NOx and organic compounds such as dioxins, are not effectively implemented in WTE facilities in China [83]. The result is a risk of unsteady and unstable combustion flame, incomplete combustion of the waste and consequent formation of air pollutants. Local residents living around existing or planned projects vigorously oppose WTE plants [87]. They mistrust the scarce information provided by utility companies and local authorities[xiv], and demand that WTE plants be located at great distance from urban centres. This distance limits the possibility to use the heat in urban DH networks. The loss is noticeable considering that in the 15 provinces of northern China, nearly 32.4 million tons of MSW per year are collected in urban areas [88] and this could provide an estimated 0.028 EJ of heat for DH, corresponding to 1% of DH demand[xv].

Our anchoring analysis showed that the coal-based regime and the MSW niche have little interaction. Social interactions are limited since there is no evidence of hybrid actors or collaboration between niche and regime actors. In each city many SMEs manage the incineration of MSW for electricity production and these companies are normally not involved in the supply of coal or the transformation of coal into DH. A major opportunity for the niche is its competitiveness against the regime. The opportunity cost of MSW-based heat is very low, since the heat is currently a waste product of MSW electricity production [82]. The major obstacle to niche expansion is related to the incapacity of its technologies and knowledge to address landscape pressure. MSW-based DH can cause soot and dioxide air pollution through incomplete combustion when the MSW is not appropriately handled. As a consequence, projects too close to urban centres face strong opposition. This barrier also limits the positive effects of the technical anchoring of the niche resulting from the possibility to co-fire MSW with coal to produce DH.

In summary, the MSW niche shows some potential as an alternative energy source for DH. It can supply heat in each city for the production of DH at competitive prices. However, important barriers to niche expansion are the incapacity to address landscape pressure and, in particular, to reduce air pollution and the consequent need to locate WTE facilities at a great distance from urban centres. This result is reinforced by the mistrust of

[xiv] Even though the recent emission standards for MSW incineration are close to the standards enforced in the EU [101].

[xv] The estimate assumes 35% of the MSW collected is incinerated; average calorific value of MSW 5 MJ/kg [102]; 50% heat conversion efficiency.

the local population in the companies and authorities responsible for environmental and health management.

6.6. Industrial waste heat

In recent years, the industrial sector has consumed on average two-thirds of national energy consumption. Energy-intensive industries such as steel, non-ferrous, petroleum, chemical, construction and pulp and paper shared about two-thirds of the industrial energy consumption [14]. At the same time, these industries generate waste heat, which can be used to supply DH systems. It is estimated that at least 50% of industrial energy is discharged into the environment in the form of mostly low-grade heat (below 200 °C) [89]. In northern China this amounts to about 7.6 EJ, or 3 times the annual energy demand of district heating in that region [14].

The productive use of waste heat has long been seen as one of the key measures of energy efficiency in China. Firstly, it is economical since waste heat is an industrial by-product. Resources of low-grade waste heat are largely underexploited compared with the relatively mature market for high-grade waste heat, in particular in the steel and cement sector [89]. Currently there are only a handful of demonstration projects utilising low-grade waste heat, e.g. Chifeng [14], Shijiazhuang [90], Qianxi [91] and Tangshan [92]. Although on average the payback time is between 4–6 years for waste heat power generation, the high initial investment creates barriers for application in industrial SMEs [93].

In addition, the exploitation of industrial low-grade waste heat suffers from challenges related to infrastructure and the uncertainty of heat supply. For instance, the feasibility of a DH system requires sufficient heat demand to be available nearby. However, industrial zones are normally built in remote areas far from large cities. Thus, extensive pipelines need to be built to connect heat suppliers and consumers. A suitable distance is considered to be between 5–10 km for a small-scale town and 20–30 km for a medium to large city [14]. Moreover, the low-efficient district heating infrastructure that require high return temperature further inhibit the economic viability of utilizing low-grade heat [91]. The uncertainty and fluctuation of heat supply also creates technical challenges for peak load management and piping network safety. These features indicate that industrial waste heat cannot be utilized alone as heating source [94].

The policy support needed to deploy projects is currently lacking. The financial barriers can be eliminated through industrial ESCOs projects. Support could also be made available through energy efficiency funds, under the framework of the 12th Five-Year Plan on industrial energy efficiency, but so far none of the policies specifically targets use of low-grade waste heat.

The anchoring analysis showed that the industrial waste heat niche maintains a limited level of interactions with the coal regime. We observed no social anchoring, since niche actors do not interact with regime actors. Regarding institutional anchoring, although this niche benefits from competitive costs, it is so far still neglected by policy makers. Technological anchoring shows important opportunities for niche deployment. Since most industries are fuelled by coal, the niche promotes more efficient use of coal-based heat, so it can deal with landscape pressure on the regime.

Table 1. Summary of the structural components of different niches and niche-regime interactions in the district heating system.

Niche	Socio-technical structure	Niche-regime interactions - Anchoring
Natural gas	*Technology:* Combustion-based CHP and HOB.	*Social:* No anchoring of gas actors with coal actors in upstream system; anchoring downstream.
	Actors: Three large companies - oligopoly.	
	Institutions: "Coal to gas" replacement locally; gas price regulation reform.	*Institutional:* Not economically competitive against coal DH; policy support for replacement of coal with natural gas DH.
	Infrastructure: Gas supply shortage; insufficient transmission pipelines.	*Technological:* Compatible with coal technologies; able to address landscape tensions.

Table 1. Summary of the structural components of different niches and niche-regime interactions in the district heating system.
(continues)

Niche	Socio-technical structure	Niche-regime interactions - Anchoring
Biomass (pellets)	*Technology:* Combustion-based CHP and HOB. *Actors:* Small to medium-sized companies. *Institutions:* "Coal to biomass boilers" replacement locally. Not enough incentives, lack of boiler standards and no market entry regulations. *Infrastructure:* Limited supply of feedstock.	*Social:* No anchoring of gas actors with coal actors in upstream system; anchoring downstream only when biomass and coal are co-fired. *Institutional:* Not economically competitive against coal DH; policy support for replacement of coal with biomass DH. *Technological:* Compatible with coal technologies. Can address landscape tensions to some extent, e.g. in a selected case the biomass boiler emitted 93% less SO^2 and 29% less soot emissions.
Geothermal direct use	*Technology:* Mechanical system (geology-dependent). *Actors:* Oil industry (Sinopec as the main player). *Institutions:* Targets for expansion of geothermal energy use. *Infrastructure:* Resource availability geography-dependent.	*Social:* No anchoring, since niche actors do not interact with regime actors. *Institutional:* Generally poorly competitive against coal-based DH. However, operating costs are highly competitive to coal-based DH where resources are available; Policy support only available since 2013. *Technological:* Not compatible with coal technologies; able to address landscape pressures since it emits almost zero emissions.
Ground source heat pump	*Technology:* Mechanical system. *Actors:* Small to medium-sized companies. *Institutions:* Varies between cities, some are equipped with full policy package, some cities against. Traditionally not considered geothermal energy, lack of regulations and quality control. *Infrastructure:* Open-loop technology misused in some regions where groundwater resources are scarce.	*Social:* No anchoring of geothermal direct use actors with coal actors. *Institutional:* Heat pump-based DH is economically competitive. On average upfront costs are 1-3 times greater than for coal-based DH systems, while the operating costs are between 30% and 70% smaller; policy support available at national level and in some cities; in water-scarce regions, there are important technical and institutional barriers. *Technological:* Not compatible with coal technologies; able to address landscape pressures, i.e. one unit of electricity required to produce three units of heat.

Table 1. Summary of the structural components of different niches and niche-regime interactions in the district heating system. *(continues)*

Niche	Socio-technical structure	Niche-regime interactions - Anchoring
Municipal solid waste (MSW)	*Technology:* Combustion-based. *Actor/network:* Electricity utilities. *Institution:* Government support, local opposition. *Infrastructure:* Inappropriate resource sorting system and technical handling, usually located far from urban areas to avoid air pollution in cities.	*Social:* Industrial actors do not involve hybrid actors or collaborations with regime actors. *Institutional:* Heat from MSW plants is released into the environment, its recovery is highly economically competitive to coal; policy support is lacking and there is public opposition at local level. *Technological:* Compatible with coal technologies; able to address landscape pressures, but in practice MSW plants emit soot and dioxide air pollutants due to incomplete combustion.
Industrial waste heat	*Technology:* Heat exchanger, heat pump etc. *Actor/network:* Main industry sector. *Institution:* Low-grade heat not supported. *Infrastructure:* Industrial zones are usually far from urban areas.	*Social:* No anchoring of industrial actors with regime actors. *Institutional:* Faces upfront costs relevant to the infrastructure settings, but industrial waste heat is affordable as a by-product of industrial processes; policy support for use of low-grade heat currently lacking. *Technological:* Symbiosis since it promotes energy efficiency of regime; it can address landscape pressures.

Overall, the industrial waste heat niche has large resource potential and important technical and institutional interactions with the regime. The challenges lie in the high upfront cost, the uncertainty and fluctuation of heat supply and, often, the long distance between industrial zones and urban DH networks.

7. Discussion and Conclusions

This study explored the dynamics and possibility for an energy transition in the Chinese DH system, and the results provide a rich systematic picture of the DH system. The system has been, and will long continue to be, characterised by the dominance of coal, a regime that remains highly stable. Factors internal to the socio-technical regime which promote its stability are the large availability of domestic resources, the competitive price of coal as an energy source for DH and support from powerful regime actors. While DH is one of the last vestiges of Chinese social welfare, coal-based DH is entering a period characterised also by challenges. Some of these originate within the coal regime, e.g. further energy efficiency improvements and more stringent policies to curb overall coal consumption and coal-related emissions. They contribute to challenge the dominance and stability of the coal regime.

Analysis of the socio-technical systems of niches indicated that there are several viable alternatives to coal-based DH and that these have been deployed to various degrees in China. Each niche has specific features in terms of structural components and interactions with the coal regime. However, here we categorised the niches into three groups with reference to the barriers they face, the opportunities they entail and their brief prospective for transition.

- The natural gas and biomass niches have barriers in terms of limited domestic supply and high production costs. However, they share a high degree of technical compatibility with the technologies and knowledge of the regime. This represents a significant opportunity for these niches. Gas alone provided more than 15% of the heat distributed through DH networks in 2012. This is also the result of policy support for these niches in recent years at national and local level. The perspectives of these niches are now largely dependent on favourable top-down institutional environments.
- The geothermal energy (direct use and GSHP) niches share similar opportunities in terms of operating costs and capacity to address landscape pressure. However, they suffer from infrastructural and institutional barriers. The expansion of the direct use niche has been largely hindered by the geographical distribution of the resource, while local regulatory bans have hindered the deployment of GSHPs in some regions. In addition to this regional specificity, the niches share a lack of interactions with the incumbent regime. In their isolation from the regime, these niches have begun to expand in regions where regulations, standards and other forms of institutional support are present. The perspectives of these niches are predominantly driven by their increasing economic returns and bottom-up support from industrial actors.
- The MSW and industrial waste heat niches are similar in that their diffusion beyond pilot cases has barely started, with only a handful of cases of industrial waste heat-based DH. They both face infrastructural barriers, since heat production units are usually located at great distance from urban centres. However, the potential is considerable, in particular industrial waste heat could provide an estimated 7.6EJ of heat to DH networks. Moreover, the operational cost of both niches is very low and thus they can be seen as competitive against coal-based DH. Their interactions with the regime have been very limited in the past and unable to support their expansion. The perspectives for expansion are hindered by lack of supportive institutional environments for low-grade waste heat utilization.

Landscape factors affect the regime and the socio-technical niches alike. This analysis identified factors able to strengthen the stability and dominance of the coal regime. These include the increasing demand for DH, mainly due to expansion of the urban population and higher standard of living. Meanwhile, the landscape also generates challenges for the coal regime. In particular, social discontent with air quality in urban centres and the need to reduce GHG emissions have resulted in public policies establishing emission controls and the replacement of coal with other energy sources. In this context, the niches that are able to address landscape challenges enjoy more favourable prospects. However, with the exception of natural gas, there are currently few public policies and programmes designed to recognise and promote such niches.

The analytical framework applied in this study provided useful insights into the dynamics and opportunities for an energy transition in the Chinese DH system. The analysis focused on the exogenous and endogenous factors that are able to influence the likelihood of energy transition, including structural components of the socio-technical regime and niches, and interactions between the niches and the regime in the context of changing landscape pressure. In some case, niches have expanded because of strong institutional and technological anchoring, despite the presence of structural barriers within the socio-technical niche. In other cases, niches have expanded due to locally favourable conditions despite a lack of supportive niche-regime interactions. A more refined analytical framework would cover a wider range of interactions, including niche-niche interactions and regime-regime interactions [95], e.g., coal regime in the electricity sector. Another important addition to the analysis of each socio-technical niche would be the inclusion of actor/network assessment [96]. However, this would require collection of large amounts of data about the (mainly) informal connections between actors in each niche.

Although DH systems offer technical opportunities to integrate different sources of energy and utilise resources that are difficult to employ in individual heating systems, the coal regime is particularly resistant to change. In this context, an integrated energy planning approach should be adopted in particular to address infrastructural and institutional barriers that this study found to be inhibiting niches' expansion.. At the local level, one can envisage future DH systems employing several alternative energy sources as a complement to coal. For transition to this more diversified system, government must create a supportive institutional environment. This is currently available only for the natural gas niche. However, considering the opportunities provided by many niches in terms of physical potential, capacity to address landscape pressures and economic viability, attention from policy-makers is needed to initiate the emergence of all niches that can contribute to this energy transition. National policymakers could learn from the experience gathered in the past decade with the deployment of renewable electricity. Following the example of the renewable electricity programme introduced in "China's Renewable Medium and Long-term Plan", an energy transition could be set in motion in the DH sector in coming years.

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9. References

[1] Xiao Q, Ma Z, Li S, Liu Y. The Impact of Winter Heating on Air Pollution in China. PLoS One [Internet]. 2015;10. Available from: *http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0117311*

[2] Xiong W, Wang Y, Mathiesen BV, Lund H, Zhang X. Heat roadmap China: New heat strategy to reduce energy consumption towards 2030. Energy [Internet]. Elsevier Ltd; 2015;81:274–85. Available from: *http:// linkinghub.elsevier.com/retrieve/pii/S0360544214014066*

[3] UNEP. District Energy in Cities - Unlocking the Potential of Energy Efficiency and Renewable Energy [Internet]. 2015. Available from: *http://www.unep.org/energy/portals/ 50177/DES_District_Energy_Report_full_02_d.pdf*

[4] Nikolaos M, Dimitrios R, Evangelia M, Panagiotis G. Introduction of renewable energy sources in the district heating system of Greece. Int J Sustain Energy Plan Manag [Internet]. 2014;04:43–56. Available from: *http://journals.aau.dk/ index.php/sepm/article/view/685/931*

[5] Xiong W. Personal Communication. 2015.

[6] National Bureau of Statistics of China. China Statistics Yearbook 2012. 2012.

[7] MOHURD. China Urban Construction Statistical Yearbook 2012 (In Chinese). 2012.

[8] MOHURD. The 12th-Five year plan on energy efficient buildings (In Chinese). 2012.

[9] Chen X, Wang L, Tong L, Sun S, Yue X, Yin S, et al. Energy saving and emission reduction of China's urban district heating. Energy Policy [Internet]. Elsevier; 2013;55:677–82. Available from: *http://dx.doi.org/ 10.1016/j. enpol.2012.12.032*

[10] Zhen L, Lin DM, Shu HW, Jiang S, Zhu YX. District cooling and heating with seawater as heat source and sink in Dalian, China. Renew Energy [Internet]. 2007;32:2603–16. Available from:*http://www.sciencedirect.com/science/ article/pii/S0960148107000055*

[11] Sun C. Geothermal direct use in three areas of China. In: World Geothermal Conference. Harpa, Iceland; 2013.

[12] Wang JJ, Xu ZL, Jin HG, Shi GH, Fu C, Yang K. Design optimization and analysis of a biomass gasification based BCHP system: A case study in Harbin, China. Renew Energy [Internet]. Elsevier Ltd; 2014;71:572–83. Available from: *http://dx.doi.org/10.1016/j.renene.2014.06.016*

[13] Sun F, Fu L, Zhang S, Sun J. New waste heat district heating system with combined heat and power based on absorption heat exchange cycle in China. Appl Therm Eng [Internet]. Elsevier Ltd; 2012;37:136–44. Available from: *http://dx.doi.org/10.1016/j.applthermaleng.2011.11.007*

[14] Fang H, Xia J, Zhu K, Su Y, Jiang Y. Industrial waste heat utilization for low temperature district heating. Energy Policy [Internet]. Elsevier; 2013;62:236–46. Available from: *http://dx.doi.org/10.1016/j.enpol.2013.06.104*

[15] Jun P, Jian W, Zhong M, Liang L, Zhang T. Air pollution abatement effects of replacing coal with natural gas for central heating in cities of China (In Chinese). China Environ Sci [Internet]. 2015;35(1):55–61. Available from: *http://www.cnki.com.cn/Article/CJFDTotal-ZGHJ201501010.htm*

[16] World Bank. Enhancing the institutional model for district heating regulation_: outside perspectives and suggestions. Energy Sector Management Assistance [Internet]. Washington D.C.; 2012. Available from:*http://documents. worldbank.org/curated/en/2012/12/18481031/enhancing-institutional-model-district-heating-regulation-outside-perspectives-suggestions*

[17] Østergaard PA, Sperling K. Towards sustainable energy planning and management. Int J Sustain Energy Plan Manag. 2014;01:1–6.

[18] Rip a, Kemp R. Technological Change. In: Human Choice and Climate Change [Internet]. 1998. p. 327–99. Available from: *http://doc.utwente.nl/34706/1/K356.pdf*

[19] Geels FW. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res Policy [Internet]. 2002;31:1257–74. Available from: *http://dx.doi.org/10.1016/S0048-7333(02)00062-8*

[20] National Bureau of Statistics of China. China Statistics Yearbook 2014 (In Chinese) [Internet]. 2015 [cited 2014 Jul 2]. Available from: *http://data.stats.gov.cn/easyquery.htm?cn=C01*

[21] NRDC and MOHURD. Guidelines on establishing the linkage between coal and heat prices (In Chinese). China; 2005.

[22] China urban heating association. Introduction of the Chinese urban heating association [Internet]. 2013. Available from: *http://www.china-heating.org.cn*

[23] Tsinghua University Building Energy Efficiency Research Center. Annual report on China building energy efficiency. Beijing; 2013.

[24] MOHURD etc. Guidelines on urban district heating system reform pilots (In Chinese). China; 2003.

[25] Chen X. Heat metering reform: 8 years of experiences. Energy efficiency and environmental protection (In Chinese) [Internet]. 2011;26–34. Available from: *http://lib.cnki.net/cjfd/BJJN201112010.html*

[26] The research group on energy consumption and energy efficiency policy in urban China. The urban energy consumption characteristics and its energy efficiency pathways (In Chinese). Beijing: China Building Industry Press; 2010.

[27] Geels F. The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930). Technol Anal Strateg Manag [Internet]. 2005;17(4):445–76. Available from: *http://dx.doi.org/10.1080/09537320500357319*

[28] Kemp R, Rip A, Schot JW. Constructing Transition Paths Through the Management of Niches. In: Garud R, Karnoe P, editors. Path Dependence and Creation [Internet]. Mahwa (N.J.) and London: Sage Publications, Inc.; 2001. p. 269–99. Available from: *http://doc.utwente.nl/42568/*

[29] Geels FW. From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Res Policy [Internet]. 2004;33:897–920. Available from: *http://www. sciencedirect. com/science/article/pii/S0048733304000496#*

[30] Schot J. The usefulness of evolutionary models for explaining innovation. The case of the Netherlands in the nineteenth century. Hist Technol [Internet]. 1998;14(July 2015): 173–200. Available from: *http://www.tandfonline. com/doi/abs/10.1080/07341519808581928*

[31] Driel HV (Hugo), Schot J. Radical Innovation as a Multilevel Process: Introducing Floating Grain Elevators in the Port of Rotterdam. Technol Cult [Internet]. 2005;46(1):51–76. Available from: *http://www.jstor.org/stable/40060795*

[32] Geels FW, Schot J. Typology of sociotechnical transition pathways. Res Policy [Internet]. 2007;36(August 2003):399–417. Available from:*http://www.sciencedirect. com/science/article/pii/S0048733307000248*

[33] Elzen B, Leeuwis C, Mierlo BC Van. Anchorage of Innovations: Assessing Dutch efforts to use the greenhouse effect as an energy source [Internet]. 2008. Available from: *http://edepot.wur.nl/2720*

[34] Elzen B, Barbier M, Cerf M, Grin J. Farming Systems Research into the 21st Century: The New Dynamic: Chapter 19 [Internet]. Darnhofer I, Gibbon D, Dedieu B, editors. 2012. 431-455 p. Available from: *http://oro.open.ac.uk/34055/*

[35] Tu KJ, Johnson-reiser S. Understanding China ‘ s Rising Coal Imports [Internet]. 2012. Available from: *http://carnegieendowment.org/files/china_coal.pdf*

[36] Zhang L. Review of Chinese coal industry development in 2013 (In Chinese) [Internet]. 2014 [cited 2014 Nov 20]. Available from: *http://www.mlr.gov.cn/ xwdt/jrxw/201401/t20140120_1301574.htm*

[37] Danish Energy Agency. Memo: District heating and combined heat and power in China [Internet]. 2013. Available from: *http://www.thinkchina.ku.dk/resources/greengrowth/Ole_Odgaard_District_heating_and_combined_heat_and_power_in_China.pdf*

[38] National Planning Commission. Regulations on combined heat and power development (In Chinese). 2000.

[39] General Office of the State Council of China. Energy Development Strategy Action Plan (2014-2020) (In Chinese) [Internet]. 2014 [cited 2015 Apr 10]. Available from: *http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm*

[40] National Bureau of Statistics of China. 2014 yearly statistic report on national economic and social development in China (In Chinese) [Internet]. 2015 [cited 2015 Apr 10]. Available from: *http://www.stats.gov.cn/tjsj/zxfb/201502/t20150226_685799.html*

[41] Ministry of environmental protection of PRC. Annual report on China environmental quality 2012 (In Chinese) [Internet]. Beijing; 2013. Available from: *http://www.mep.gov.cn/gkml/hbb/qt/201306/W020130604382172090857.pdf*

[42] NRDC. Guidelines on the mechanism to coordinate coal production and transportation with demand (In Chinese). 2009.

[43] Xinhua News. PM2.5 over 900 in Beijing’s air quality monitoring sites (In Chinese) [Internet]. 2013 [cited 2013 Feb 2]. Available from: *http://news.xinhuanet.com/local/2013-01/13/c_114345597.htm*

[44] Laurent É. Inequality as pollution , pollution as inequality: the social-ecological nexus [Internet]. 2014. Available from: *https://ces.fas.harvard.edu/files/ events/ 20130918_VS_Laurent_InequalityAsPollution.pdf*

[45] Lewis J. Energy and Climate Goals of China ' s 12th Five - Year Plan [Internet]. 2011. Available from: *http://www.c2es.org/international/key-country-policies/china/energy-climate-goals-twelfth-five-year-plan*

[46] Office of the Press Secretary of The White House. U.S.-China Joint Announcement on Climate Change [Internet]. 2014 [cited 2014 Nov 13]. Available from: *http:// www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change*

[47] The World Bank and Development Research Center of the state Council of PRC. Urban China: toward efficeint, inclusive, and sustainable urbanization [Internet]. Washington D.C., USA; 2014. Available from: *https://openknowledge.worldbank.org/handle/10986/18865*

[48] Climate Policy Initiative. Buildings Energy Efficiency in China, Germany, and the United States Climate Policy Initiative [Internet]. San Francisco, USA; 2013. Available from: *http://climatepolicyinitiative.org/wp-content/uploads /2013/04/Buildings-Energy-Efficiency-in-China-Germany-and-the-United-States.pdf*

[49] National Energy Agency of China. China renewable energy 12th five-year plan summary (In Chinese) [Internet]. Beijing; 2012 [cited 2013 Aug 1]. Available from: *http://www.nea.gov.cn/2012-08/08/c_131767651.htm*

[50] Ministry of Land and Resource of China. Conventional natural gas is abundant, its potential is larger than oil (In Chinese) [Internet]. 2015 [cited 2015 May 18]. Available from: *http://www.mlr.gov.cn/ xwdt/jrxw/201505/ t20150506 _1349846.htm*

[51] CNPC Research Institute of Economics and Technology. International and domestic oil and gas sector report 2013 (In Chinese) [Internet]. 2014 [cited 2014 Jul 2]. Available from: *http://www.gov.cn/gzdt/2014-01/20/content_2570732.htm*

[52] National Bureau of Statistics of China. China energy statistics 2012 (In Chinese) [Internet]. Beijing; 2012. Available from: *http://data.stats.gov.cn/workspace/ index? m=hgndv*

[53] Dong J, Zhang X, Xu X. Techno-economic assessment and policy of gas power generation considering the role of multiple stakeholders in China. Energy Policy [Internet]. Elsevier; 2012;48:209–21. Available from: *http://dx.doi.org /10.1016/j.enpol.2012.05.010*

[54] IEA. Gas Pricing and Regulation: China's challenges and IEA experience [Internet]. Paris; 2012. Available from: *http://www.iea.org/publications/freepublications/publication/ chinagasreport_final_web.pdf*

[55] Chen M. The Development of Chinese Gas Pricing_: Drivers, Challenges and Implications for Demand [Internet]. 2014. Available from:*https://www.oxfordenergy.org/ 2014/07/the-development-of-chinese-gas-pricing-drivers-challenges-and-implications-for-demand/*

[56] NDRC. Natural gas price adjustments No. 1246 (In Chinese) [Internet]. 2013 [cited 2015 May 22]. Available from: *http://www.sdpc.gov.cn/zwfwzx/zfdj/jggg/tyq/201306/t201306 28_547973.html*

[57] Qinhuangdao Coal Trade Market ltd. Bohai-rim Steam-Coal Price Index (In Chinese) [Internet]. 2015 [cited 2015 May 22]. Available from: *http://www.osc.org.cn/ CoalIndex/ en/new/*

[58] USEPA. Environmental impact of natural gas [Internet]. 2013 [cited 2014 Apr 1]. Available from: *http://www.epa.gov /cleanenergy/energy-and-you/affect/natural-gas.html#footno tes*

[59] Han W. R&D of China's Strategic New Industries: Biomass energy (In Chinese). Beijing, China: China Machine Press; 2013.

[60] National Energy Agency. 12th Five-year Plan for biomass (In Chinese) [Internet]. 2012 [cited 2013 Aug 1]. Available from: *http://zfxxgk.nea.gov.cn/auto87/201212/t20121228_1568.htm*

[61] Wei W, Zhang X. Development status and prospect of solid biofuel-preparation in China (In Chinese). Guangdong Agric Sci [Internet]. 2012;(5):135–8. Available from: *http://xuewen.cnki.net/CJFD-NJXN200903006.html*

[62] Hong H, Yu W, Song B, Zhang X. An Empirical Study on Industrialization of Biomass Briquette in China (In Chinese). Resour Sci [Internet]. 2010;32(11):2172–8. Available from: *http://www.resci.cn/ch/reader/view_abstract.aspx?file_no=2 0101119*

[63] Han W. R&D of China's Strategic New Industries: Biomass energy (In Chinese). Beijing, China: China Machine Press; 2013. 85 p.

[64] National Energy Agency and Ministry of Environment Protection. Demonstration projects on biomass boiler heating No. 295 (In Chinese) [Internet]. 2014 [cited 2015 May 22]. Available from: *http://zfxxgk.nea.gov.cn/ auto87/201407/ t20140708_1818.htm*

[65] National Energy Agency and Ministry of Environment Protection. Guidelines on biomass boiler heating demonstration projects No. 520 (In Chinese) [Internet]. 2014 [cited 2015 May 22]. Available from: *http://zfxxgk.nea.gov.cn/auto87/201412 /t20141226_1875.htm*

[66] Peng Y, Zhong M. Compacted biomass fuels and coal price ratio relationship study in China (In Chinese). Econ issues insights [Internet]. 2013;(9):8–14. Available from: *http://mall.cnki.net/magazine/Article/JJWS201309003.htm*

[67] Liying S, Yishui T, Haibo M. Compacted biomass fuel CDM developments in China (In Chinese). 2011;27(8):304–7. Available from: *http://lib.cnki.net/cjfd/NYGU201108056.html*

[68] Wang G, Li K, Wen D, Lin W, Lin L, Liu Z, et al. Assessment of geothermal resources in China. In: Thirty-eightth Workshop on Geothermal Reservoir Engineering [Internet]. Palo Alto, CA; 2013. Available from: *https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2013/Wang.pdf*

[69] Zheng K, Han Z, Zhang Z. Steady Industrialized Development of Geothermal Energy in China Country Update Report 2005-2009. In: Proceedings World Geothermal Congress 2010 [Internet]. Bali, Indonesia; 2010. Available from: *http://www.geothermal-energy.org/pdf/ IGAstandard/WGC/2010/0136.pdf*

[70] National Energy Agency of China. Guidelines on promoting geothermal energy development and utilization(In Chinese) [Internet]. 2013 [cited 2014 Apr 1]. Available from: *http://zfxxgk.nea.gov.cn/auto87/201302/t20130207_1581.htm*

[71] Geothermal energy Association. Environmental benefits of geothermal energy [Internet]. 2014 [cited 2014 Oct 2]. Available from: *http://geo-energy.org/geo_basics_environment.aspx*

[72] Wang S. Utilization of Geothermal Energy in New Countryside Construction (In Chinese). J Anhui Agri Sci [Internet]. 2012;40(30):14895–6, 14936. Available from: *http://cnki.cgl.org.cn /KCMS/detail/detail. aspx?filename=AHNY201230102&dbcode=CJFQ&dbname=CJFD2012*

[73] Zhu Q. Application and development of ground-source heat pump in China (In Chinese) [Internet]. 2012. Available from: *http://www2.china.ahk.de/download/econet/9.Dr.ZhuQingyu.pdf*

[74] Zhang K, Liao P. Ontology of ground source heat pump. Renew Sustain Energy Rev [Internet]. Elsevier; 2015;49:51–9. Available from: *http://dx.doi.org/10.1016/j.rser.2015.04.021*

[75] MOHURD and MOF. The opinions on further promoting application of renewable energy in buildings (No.61) (In Chinese) [Internet]. 2011 [cited 2013 Aug 1]. Available from: *http://jjs.mof.gov.cn/zhengwuxinxi/tongzhigonggao/201103/t20110314_500932.html*

[76] Geng Y, Sarkis J, Wang X, Zhao H, Zhong Y. Regional application of ground source heat pump in China: A case of Shenyang. Renew Sustain Energy Rev [Internet]. 2013;18(72):95–102. Available from: *http://www.sciencedirect. com/science/article/pii/S1364032112005576*

[77] Ma Z, Yao Y, Jiang Y, Ni L. Risks for next generations if groundwater source based heatp pump do not rejct 100% water back to underground reservoir (In Chinese). Cool Technol [Internet]. 2007;4:5-8. Available from: *http://www.cnki.net/KCMS/detail/detail.aspx?filename=ZLJS200704000&dbname=cjfqtotal&dbcode=CJFQ&v=MTU3MjRmYkc0SHRiTXE0OUZaSVI2RGc4L3poWVU3enNPVDNpUXJSY3pGckNVUkwrZlp1UnZGQ3JtVmJyQlB5SEI=*

[78] City government of Nanjing. Regulations of underground water resrouce protection in Nanjing (In Chinese) [Internet]. 2013 [cited 2015 May 29]. Available from: *http://www.nanjing.gov.cn/njszf/ szf/ 201307/t20130703 _1183608.html*

[79] Zhang B, Yu Z, Bai X, Zhang C. Energy and economic savings of ground-source heat pump technology for heating and cooling (In Chinese). Nat Resour Econ China [Internet]. 2011;(4):24–6. Available from: *http://cnki.cgl.org.cn/kcms/detail/detail.aspx?DbCode=CJFQ&file name=ZDKJ201104007*

[80] DOE. Benefits of geothermal heat pump systems. 2014.

[81] MOHURD. China urban construction statistical yearbook 2009 (In Chinese). 2009.

[82] Dorn T, Flamme S, Nelles M. A review of energy recovery from waste in China. Waste Manag Res [Internet]. 2012;30:432–41. Available from: *http://wmr.sagepub.com/content/30/4/432.long*

[83] Cheng H, Hu Y. Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China. Bioresour Technol [Internet]. Elsevier Ltd; 2010;101(11):3816–24. Available from: *http://dx.doi.org/10.1016/j.biortech.2010.01.040*

[84] Chen X, Geng Y, Fujita T. An overview of municipal solid waste management in China. Waste Manag [Internet]. Elsevier Ltd; 2010;30(4):716–24. Available from: *http://www.sciencedirect.com/science/article/pii/S0956053X09004590#*

[85] Yang N, Zhang H, Chen M, Shao LM, He PJ. Greenhouse gas emissions from MSW incineration in China: Impacts of waste characteristics and energy recovery. Waste Manag [Internet]. Elsevier Ltd; 2012;32(12):2552–60. Available from: *http://www.sciencedirect.com/science/article/pii/S0956053X12002784*

[86] MSW incineration standard working group. Municipal solid waste incineration emission control standard: Draft for comments (In Chinese) [Internet]. 2013. Available from: *http://www.zhb.gov.cn/gkml/hbb/bgth/201312/W020131230365247732252.pdf*

[87] Zhang C. China's waste-incineration deadlock [Internet]. 2014 [cited 2015 Jan 11]. Available from: *https://www.chinadialogue.net/article/show/single/en/7150-China-s-waste-incineration-deadlock*

[88] State Council of PRC. 12th Five-year Plan for sanitary disposal of urban solid wastes (In Chinese) [Internet]. 2012 [cited 2013 Aug 2]. Available from: *http://www.gov.cn/zwgk/2012-05/04/content_2129302.htm*

[89] Lian H, Li Y, Shu G-Y, Gu C. An overview of domestic technologies for waste heat utilization (In Chinese). Energy Conserv Technol [Internet]. 2011;29(2):123–8,133.

Available from: *http://www.cqvip.com/qk/90988x/201102/37245044.html*

[90] Xinhua News. Turning industrial waste heat into new heat source for cities (In Chinese) [Internet]. 2014 [cited 2014 Oct 1]. Available from: *http://www.he.xinhuanet.com/news/2014-09/15/c_1112477896.htm*

[91] Jiang Y. The policy measures for energy conversation in Chinese urban heating (In Chinese). In: The 11th International Conference on Green and Energy-Efficient Building & New Technologies and Product Expo [Internet]. Beijing, China; 2015. Available from: *http://www. chinagb.net/gbmeeting/igebc11/ptt/ 20150327/111934.shtml*

[92] Xinhua News. Experiments with industrial waste heat based district heating in northern China (In Chinese) [Internet]. 2015 [cited 2015 Apr 1]. Available from: *http://news.xinhuanet.com/energy/2015-03/11/c_1114605 798.htm*

[93] Dong T. The industrial waste heat utilization in China (In Chinese) [Internet]. 2013. Available from: *http://www.nsd. edu.cn/cn/userfiles/Other/2013-05/201305272101287 5688065.pdf*

[94] Fang H, Xia J. The technical challenges and solutions for the utilization of industrial waste heat in district heating (In Chinese). Dist Heat [Internet]. 2013;22–7. Available from: *http://mall.cnki.net/magazine/Article/QYGR201303006.htm*

[95] Papachristos G, Sofianos A, Adamides E. System interactions in socio-technical transitions: Extending the multi-level perspective. Environ Innov Soc Transitions [Internet]. Elsevier B.V.; 2013;7:53–69. Available from: *http://www.sciencedirect.com/science/article/pii/S2210422413000269*

[96] Hekkert MP, Negro SO, Heimeriks G, Harmsen R. Technological Innovation Systema Analysis: a manual for analysts [Internet]. 2011. Available from: *http://www.innovation-system.net/wp-content/uploads/2013/03/UU_02rapport_Technological_Innovation_System_Analysis.pdf*

[97] Wieczorek AJ, Harmsen R, Heimeriks GJ, Negro SO, Hekkert MP. Systemic policy for offshore wind challenges in Europe [Internet]. Innovation Studies Utrecht (ISU) Working Paper Series. 2012. Available from: *http://www.geo.uu.nl/isu/pdf/isu1205.pdf*

[98] WHO. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. 2005.

[99] WHO. Public health, environmental and social determinants of health [Internet]. 2013 [cited 2013 Aug 3]. Available from: *http://www.who.int/phe/health_topics/outdoorair/databases/en/*

[100] Zheng F. Biotechnology, Agriculture, Environment and Energy. Leiden, The Netherlands: CRC Press; 2014. 68 p.

[101] Ministry of Environment Protection of China. Municipal solid waste incineration emission control standard GB18485-2014 (In Chinese) [Internet]. 2014 [cited 2014 Aug 2]. Available from: *http://kjs.mep.gov.cn/hjbhbz/bzwb /gthw/gtfwwrkzbz/201405/t20140530_276307.htm*

[102] Solenthaler B, Bunge R. Waste Incineration in China [Internet]. Rapperswil, Switzerland; 2003. Available from: *http://www.seas.columbia.edu/earth/wtert/sofos/Waste_Incineration_China.pdf*

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Appendix 1: Interview template

1. Do you have statistics on:
    a. The **shares of different energy sources to the** DH system?
    b. The shares of CHP, big boilers and small/distributed boilers in DH?
    c. Heat production **costs**
    d. Heating **prices**? How are prices established?
2. What are the **technologies** used to supply the heat to DH (E.g. CHP, boilers, CSP, heat pumps)? Any advanced technology currently at R&D level?
3. What are the main **national policies** for heating (or in electricity) that affect the DH sector?
4. What are the main types of **local policies** for DH (some examples)?
5. Who are the **actors** most active in the sector? Are energy companies interested in DH? Does DH have an important role in deciding which energy source to use? Is the national government interested in switching energy source away from coal? Do real estate developers have a say in the choice of energy source?
6. How does the energy supply for DH in China fit/compare with the national plans for the use of renewables **for electricity** in China?
7. More….

Notes

The interview template is designed to assist the analysis of niche innovation system and niche-regime anchoring, in addition to the data collected from various publications. The template is a general framework for all interviews. We aimed to cover the basic data for technology, economics, actor and institution of each niche. In practice, we revised each question slightly to fit into the characteristics of each niche, as well as the conversation flow went with the interviewees.

The conversation was conducted in Chinese in Beijing between July-Sep 2013. Interviewees include: Heating reform office at Ministry of Housing, Urban and Rural Development, Chinese urban district heating association, China geothermal association, Danish district heating association (Beijing office), Swedish district heating association (Beijing office), and experts in other alternative energy sectors (Tsinghua University, Beijing Forestry University and China Architecture Science and so on).